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(56) Documents Cited
GB 2134265 A **US 4635201 A**

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(54) Abstract Title
Measuring engine speed from an engine speed signature

(57) An apparatus and method are provided for determining the rotational speed of an internal combustion engine. The method involves determining an engine speed signature for the internal combustion engine and using that signature to calculate the rotational speed of the engine. The engine speed signature may be calculated using a normalized elapsed time error where the elapsed time is the time period for the engine to move between known angular positions.

In practice a calculated filtered engine speed may be derived from the filtered error between the engine speed reading and a running average of the engine speed.

FIG - 2 -

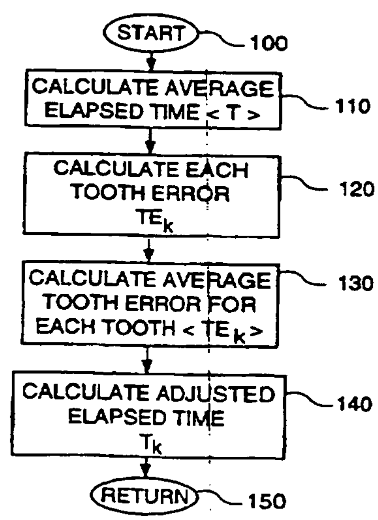

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Fig. 1

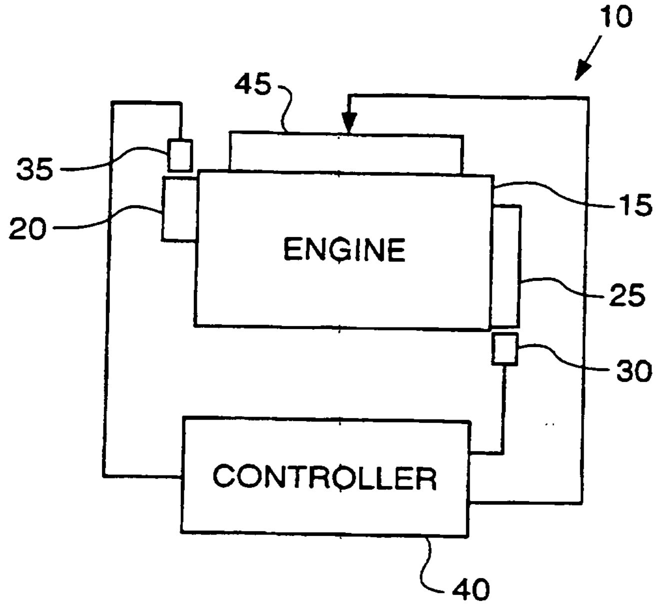

10
45
35
20
ENGINE
15
25
30
CONTROLLER
40

Fig. 2

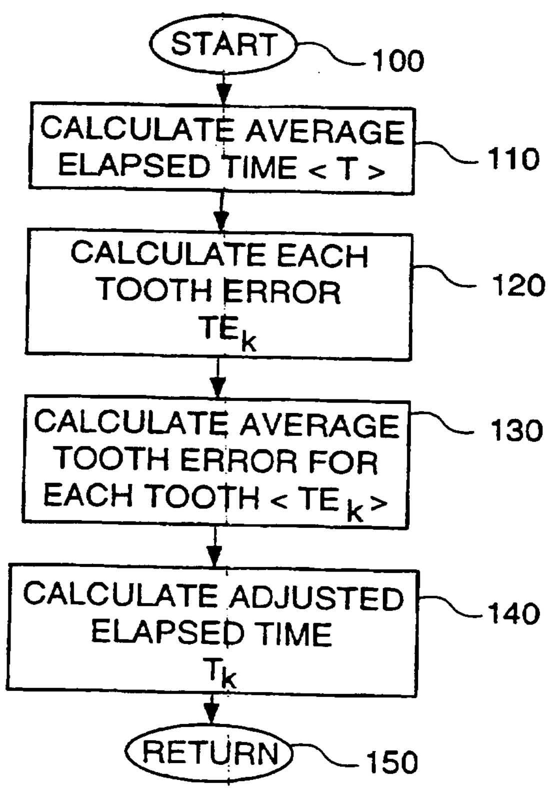
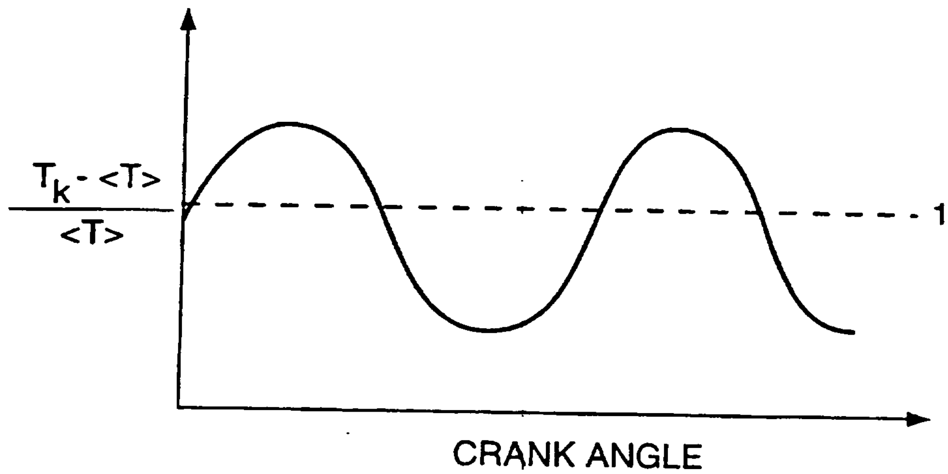

START
100
CALCULATE AVERAGE ELAPSED TIME < T >
110
CALCULATE EACH TOOTH ERROR TE k
120
CALCULATE AVERAGE TOOTH ERROR FOR EACH TOOTH < TE k >
130
CALCULATE ADJUSTED ELAPSED TIME T k
140
RETURN
150

Fig. 3



METHOD AND APPARATUS FOR MEASURING ENGINE SPEED

The present invention relates generally to an engine sensing method and apparatus, and more specifically, to a method and apparatus for sensing variations in engine speed.

In electronically controlled engines, it is often desirable to sense the rotational velocity of the engine and use that value in controlling the engine. For example, some internal combustion engines are controlled to a desired engine speed. In those cases to control the engine speed accurately, it is desirable to have an accurate measurement of the actual engine speed.

To some extent engine speed sensors are known in the prior art. One such sensor involves the use of a magneto reluctance sensor placed in proximity to an engine gear whose rotational velocity is a function of the rotational velocity of the engine. As individual teeth on the gear pass near the sensor it varies its output signal. A microprocessor is generally connected with the sensor to detect those variations in the sensor signal and measure the elapsed time between the passing of adjacent gear teeth. By knowing the number of teeth on the gear and the relationship between the number of gear revolutions to the number of revolutions of the engine it is then possible to calculate the rotational

velocity of the engine. Although these systems work fairly well there are drawbacks.

One drawback involves the speed signature for a specific engine. The rotational velocity of an internal combustion engine typically is not perfectly constant throughout an engine revolution. Instead, there are typically slight variations in speed that can result from: (1) combustion occurring in a cylinder and thereby increasing the rotational velocity; or (2) removing energy from the flywheel to compress the air/fuel mixture prior to combustion, thereby slightly decreasing the engine speed. It is undesirable for the microprocessor in such a system to mistake a slight increase in speed resulting from the engine signature as indicating an increase in overall engine speed. One way that known controls account for these deviations is to filter the elapsed time readings with a first order lag filter in an attempt to filter out the engine speed signature. However, using a filter in this manner has the associated disadvantage of creating a time lag between an actual increase in engine speed and the time when the microprocessor recognizes the increase. Known controls have typically balanced these two competing undesirable effects.

It would be preferable to have an engine speed control system that could recognize the specific speed signature of an engine and use that speed signature in the engine speed control. It would be desirable for such a system to demonstrate the characteristics of a zero order lag filter with respect to elapsed time measurements between gear teeth.

In one aspect of the present invention a method for measuring the rotational velocity of an internal combustion engine is disclosed. The method includes the steps of determining and engine speed signature for the engine and using the signature to calculate engine speed.

In another aspect of the invention an apparatus is disclosed that includes a proximity sensor placed adjacent a gear or other rotating body on the engine. The sensor produces a signal as a function of the rotation of the gear or body. A controller receives the sensor signal and calculates and engine speed signature that is an input in a calculation of engine speed.

These and other aspects and advantages of the present invention will become apparent upon reading the following disclosure in conjunction with the drawings and appended claims.

Fig. 1 is a block diagram of an engine speed control system that can be used in connection with a preferred embodiment of the invention.

Fig. 2 is a flow chart of an embodiment of the software instructions associated with a preferred embodiment of the present invention.

Fig. 3 is a representative graph showing normalized elapsed time error versus crankshaft angle for a typical engine.

The following detailed description is of the best mode of the present invention. The present invention is not limited to the single embodiment disclosed herein. Instead, the invention encompasses those other modified or varied methods and systems as may fall within the scope of the appended claims. Throughout the disclosure and the various figures like reference numbers will be used to describe like elements.

Referring first to Fig. 1, a schematic block diagram of various elements of an engine speed sensing and control system 10 is shown. Included in the engine speed sensing and control system 10 is an engine 15 preferably having fuel injectors 45, or other fuel delivery mechanisms such as a carburetor, for delivering a specified quantity of fuel to the engine cylinders (not shown). Coupled with the fuel injectors 45 is a controller 40 that delivers a fuel injection signal based on a preselected control strategy and various sensor inputs. The fuel injection signal typically determines the timing and duration of fuel injected into a specific engine cylinder.

In Fig. 1, there are two speed sensors 30, 35 shown associated with a flywheel 25 and a camshaft gear 20 on the engine 15. Typically, there are other sensor inputs involved in developing the fuel injection signal. These sensor inputs may include atmospheric pressure, manifold pressure, engine temperature, vehicle speed, transmission speed, and operator throttle setting, among others. These sensors are known to those skilled in the art, and in themselves are not part of the present invention so

are not described further. Although there are two speed sensors shown in Fig. 1, the best mode embodiment only uses a single signal from either sensor 30 or sensor 35 in carrying out the invention. Moreover, it is within the scope of the present invention to include a similar type sensor associated with a different gear or wheel so long as the rotational velocity of the gear or wheel is a function of the rotational speed of the engine. In a preferred embodiment, the sensors 30, 35 comprise a magneto reluctance type sensor. As will be apparent to those skilled in the art, however, other types of proximity sensors may be used so long as they are capable of producing a measurable signal in response to the proximity of a gear tooth.

As shown in Fig. 1, the sensors 30, 35 are electrically coupled with the controller 40. As will be described in more detail with reference to other figures, the controller 40 receives signals from the sensors 30, 35 and calculates an engine speed value that is used in the preselected control strategy to calculate a fuel injection signal that is delivered by the controller 40 to the fuel injectors 45. As is known by those skilled in the art, the controller and possibly other components, have filtering, conditioning, and protection circuitry associated with inputs to, and outputs from, those components. These known filtering conditioning and protection circuits are known to those skilled in the art; and, therefore, are neither shown in the figures nor described in more detail herein.

Referring now to Fig. 2, a block diagram of the software associated with a preferred embodiment is shown. Those skilled in the art can readily and

easily use the flowchart shown in Fig. 2, in connection with the specific programming language associated with a selected microprocessor to create the illustrated control. Block 100 is the start of the program and program control passes to block 110.

In block 110, the controller 40 identifies signals from a sensor 30 or 35, associated with each of the teeth on a respective gear 25 or 20. In a preferred embodiment, there are a known number of teeth on the gear and a known relationship between the rotational velocity of the gear and the rotational velocity of the engine. The controller measures the elapsed time T_k between adjacent teeth and assigns that value to a specific tooth k on the gear. The controller then calculates an elapsed time average $\langle T_k \rangle$ which is the average of all the measured elapsed times T_k for the previous engine cycle. The controller 40 continuously calculates the elapsed time average $\langle T_k \rangle$ each time a new elapsed time T_k is read. Program control then passes to block 120.

In block 120, once the engine has performed at least one engine cycle and thus the controller 40 has calculated an elapsed time average $\langle T_k \rangle$, then the controller 40 will preferably calculate an elapsed time error TE_k for each tooth according to the following formula:

$$(1) \qquad TE_k = T_k - \langle T \rangle$$

The errors associated with this calculation will be more pronounced at lower engine speeds, i.e., when the elapsed time between teeth is relatively longer. Thus, to account for differences in the magnitude of the elapsed time error, equation (1) above is

normalized by the average elapsed time, and the elapsed time error of equation (1) becomes as follows:

$$(2) \qquad TE_k = \frac{T_k - \langle T_k \rangle}{\langle T_k \rangle}$$

Thus, in a preferred embodiment, the controller will read an elapsed time associated with a specific tooth, calculate a form of normalized error according to equation (2), and then store that value in an array associated with that specific tooth. In this form, if the gear 20, 25 has N teeth the controller will store the values TE_k in an N x m array, where m is the depth of the array (i.e., m being the number of elapsed time error values the controller 40 will store for each specific tooth). For example, if a gear has 360 teeth, and the controller is designed to track twenty sequentially measured elapsed time errors for each tooth, then the array would be 360 x 20. If you wanted to then see the elapsed time error for tooth 210, ten revolutions ago (ten revolutions of the gear) you would look at the place (210,10) in the array. From block 120, program control passes to block 130.

In block 130, the controller calculates an average, or filtered tooth error $\langle TE_k \rangle$ for each tooth k, using the m TE_k values stored in memory. In a preferred embodiment, the controller 40 calculates a filtered tooth error for a specific tooth according to the following formula:

$$(3) \qquad \langle TE_k \rangle_{new} = \langle TE_k \rangle_{old} + K_{ff} \left(TE_k - \langle TE_k \rangle_{old} \right)$$

where K_{ff} is a time constant of a low pass filter used to determine the emphasis placed on the raw data

samples TE_k to calculate a new average elapsed time error value $< TE_k >_{new}$ for that tooth. If the K_{ff} value is high, then new samples will change the average elapsed time error value $< TE_k >$ more quickly then if the K_{ff} value is less than one, for example. Program control passes from block 130 to block 140.

In block 140, the controller 40 calculates an adjusted elapsed time $T_{k(adjusted)}$ for each tooth according to the following formula:

(4) $$T_{k(adjusted)} = (<TE_k> \exists <T_k>) + <T_k>$$

In this way, by measuring an elapsed time error for each tooth, calculating an average elapsed time error for each tooth, and subtracting the elapsed time error for each tooth from the elapsed time reading for that tooth, the controller 40 in effect removes the engine speed signature from the speed sensor readings, and permits the controller to more easily distinguish variations in engine speed. This more accurate engine speed calculation makes it more likely that the controller will be able to more accurately control actual engine speed.

Referring now to Fig. 3, a generic graph is shown demonstrating a typical relationship between the normalized engine speed error and crankshaft position. This is a typical engine speed signature for an engine and demonstrates the variation in normalized engine speed error versus crankshaft angle. By removing an element of the normalized elapsed time error from the calculation of engine speed, the controller 40 removes the engine speed error signature and produces a more accurate measurement of the actual engine speed.

Claims

1. A method for determining engine speed of an internal combustion engine, comprising:

measuring engine speed readings;

maintaining a running average of said engine speed readings;

calculating an engine speed error reading as a difference between an engine speed reading and said running average;

filtering said engine speed error reading; and

calculating a filtered engine speed as a function of said measured engine speed and said filtered engine speed error reading.

2. A method for determining an engine speed of an internal combustion engine, said engine including an engine speed sensor associated with a gear on the engine, said sensor producing timing signals as a function of gear teeth passing in proximity to said sensor; said method including the steps of:

measuring an elapsed time between predetermined passing adjacent teeth;

calculating an average elapsed time;

calculating an elapsed time error for each of said predetermined adjacent teeth, said calculation including a difference between the measured elapsed time of said passing teeth and said average elapsed time;

producing a filtered elapsed time error for each of said predetermined adjacent teeth;

calculating an engine speed as a function of said measured elapsed time and said filtered elapsed time error for each of said predetermined adjacent teeth.

3. A method for determining an engine speed of an internal combustion engine, including:

determining an engine speed signature;

using the engine speed signature to calculate engine speed.

4. The method according to claim 3, wherein said step of determining includes:

determining a plurality of engine speed components, each engine speed component having a defined relationship to the rotational position of the engine;

storing each engine speed component.

5. The method according to claim 3, wherein the step of determining includes:

measuring a plurality of elapsed times, each elapsed time associated with a rotational position of the engine;

calculating an elapsed time average;

calculating an elapsed time error; and

filtering said elapsed time errors to produce a filtered elapsed time error; and

calculating an adjusted elapsed time as a function of said elapsed time and said filtered elapsed time error.

6. The method according to claim 5, wherein said step of filtering includes:

filtering said elapsed time errors so as to produce a zero order lag on the adjusted elapsed time.

7. An apparatus for calculating the rotational velocity of an internal combustion engine, comprising:

a rotating body coupled with said engine, said rotating body having a plurality of protrusions about a circumference of said body;

a sensor located adjacent said rotating body and producing a signal as a function of individual protrusions passing adjacent said sensor;

a controller coupled with said sensor and receiving said signal, the controller calculating an engine signature as a function of said signal and using said engine signature to calculate said engine speed.

8. The apparatus according to claim 7, wherein:

said controller calculates said engine signature as a function of elapsed times between signals associated with predetermined protrusions of the rotating body.

9. The apparatus according to claim 7, wherein:

said controller calculates said engine signature as a function of elapsed times between signals associated with predetermined protrusions of the rotating body, an elapsed time error, a filtered elapsed time error, and an adjusted elapsed time.

10. An apparatus for calculating the rotational velocity of an internal combustion engine, comprising:

a gear coupled wish said engine, said gear having a plurality of teeth;

a sensor located adjacent the gear and producing a signal as a function of teeth passing adjacent said sensor;

a controller coupled with said sensor and receiving said signal, the controller calculating an engine signature as a function of said signal and using said engine signature to calculate said engine speed.

11. The apparatus according to claim 10, wherein:

said controller calculates said engine signature as a function of elapsed times between signals associated with predetermined gear teeth.

12. The apparatus according to claim 10, wherein:

said controller calculates said engine signature as a function of elapsed times between signals associated with gear teeth, an elapsed time error, a filtered elapsed time error, and an adjusted elapsed time.

13. The method of any of claims 1 to 3, substantially as described with reference to the accompanying drawings.

14. The apparatus of claim 7 or claim 10, substantially as described with reference to the accompanying drawings.

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Application No:	GB 0000224.6	**Examiner:**	Eamonn Quirk
Claims searched:	1-14	**Date of search:**	20 April 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G1N(NAHHK)

Int Cl (Ed.7): G01P (3/489)

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2 134 265 A (Diesel Kiki Co.)	
X	US 4 635 201 (Diesel Kiki Co.) Whole Document	1-3,7 10 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		